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SEWERAGE SYSTEMS.

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The writer desires to offer the Society some remarks on sewerage systems, drawn partly from a recent examination of the most interesting of such works in Europe, and partly from his own experience in this branch of engineering.

There seems to be still a considerable amount of uncertainty regarding the merits of different systems, if we judge from the continued polemics among professional men in Europe, and recent discussions in our own country.

But, as more experience is being gained, it is also noticeable that opinions are converging, and the direction in which the best solution may be found, is becoming more distinctly indicated.

To state in what the writer believes this direction to consist, is the object of this paper.

It may be well at first to direct attention to a few difficulties in the way of arriving at an impartial judgment of the matter.

In the first place, it can be noticed that the habitual engagement of the mind in certain directions of thought, will more or less tend towards a one-sided view of all outside questions, and, in thus influencing opinions, cause what might be termed a professional bias.

We can observe, in Europe, that chemists, agriculturists, and hygienists are, as a rule, prominently conspicuous in the opposition to the water-carriage system. They point to the injurious effects of soil contamination by sewers, of the gases and germs emanating from them, of river pollution and various dangers expected to arise from sewage farming, as well as to the value, as manure, of undiluted excreta, and the national importance of preventing its waste, all of which comes more or less within the special range of their professions.

On the other hand, we can notice that municipal engineers who, in addition to the sewage problem, find themselves confronted by such as the removal of storm and sub-soil water, of house refuse, the construction and cleaning of streets, the supply of water to dwellings, and its subsequent removal, and finally, by the very weighty necessity of exercising the utmost economy of expenditure in their works, are quite generally in favor of water carriage.

What seems so apparent regarding this system in its general features, may also be expected to affect the views regarding its special applications. We are, therefore, not surprised to discover a division of opinion concerning the relative superiority of the "separate" and "combined" systems, and, lastly, to find that even some details of each, form points of dispute.

Each person judges matters from his own sphere of working, and it seems that, by considering this unconscious bias and eliminating its tendency to exaggerate insignificant facts, both *pro* and *con*, and, on the other hand, by fully realizing the most essential features, we may advance a step towards truer conclusions.

For instance, the engineer ought to pay greater attention to the sani-

tary demands upon his works, and endeavor first of all to completely satisfy them, because they are the prime requirement of the system. And his opponents ought to inquire more carefully into the technical nature and necessity of correlative city requirements and works, and also into the question of municipal economy.

Our opinions on the relative merits of designs are also sometimes misguided by ignorance of the local history of existing works. It often occurs that financial considerations have caused certain features, be it with reference to a new use for old works, or to a peculiar use for new works, wh ch outsiders are apt to misinterpret.

As the physical features greatly influence designs, erroneous opinions can also easily arise from an incomplete knowledge of them.

Even the customs of the people can materially influence designs, and certain features may be acceptable in one locality and strenuously objected to in others. For this reason the system of dry removal, as practiced in some European towns where water-closets are not used, and where the exchange of casks is done under very strict surveillance, is not objectionable from a sanitary point of view, whereas in our own towns it would probably become a great nuisance.

Finally, there is a difficulty in rightly judging the works of a city, in the fact that old practices and laws are more or less hard to change. When certain customs, either in the designing or the execution of the works have prevailed for some time, they will generally be adhered to, unless absolutely faulty, and novel matters of any consequence will be adapted to the old works.

The writer thought it pertinent to mention these various points, partly because they seem to have been a prominent cause for the variety of opinions, and partly because he felt it necessary to keep them in mind when comparing the various methods and works, in order to be better able to appreciate their relative value, and to judge of their applicability in other localities.

General Systems.

We will now inquire into the several methods of removing offal and waste water from towns, and then endeavor to trace their relative merits in order to discover in what direction an ultimate agreement may be found.

Each system must be examined under two aspects. The first in importance is its sanitary value. The second is its cost. While the former should be absolute, demanding a satisfactory standard in every case, the latter is relative, depending on a great variety of conditions.

All systems should, therefore, first answer the hygienic requirement of preventing decomposition of organic matter, under conditions which permit unhealthful influences. After this object has been satisfactorily attained, the only other point of comparison is confined to the expense of construction and maintenance.

In general, two methods have been proposed to satisfy the sanitary stipulations, the so-called "dry removal" and "water-carriage." The former accomplishes its object either by temporary storage, with frequent removal, before decomposition can be rendered injurious (casks and pails), and the latter by immediate and continuous self-removal (sewerage). Let us briefly examine into the nature and applicability of each of these methods.

I.—Temporary Storage and Periodical Removal.

We have, under this head, a variety of ways in which excreta are collected and removed.

Among them, the most common in our own cities, is the storage in cesspools under or near the dwellings. The fact that these appliances require the least outlay of money is the cause of their extended use. But, because they do not comply with the sanitary requirements, by permitting decomposition near the houses, the penetration of foul liquids into the soil under them and the ready escape of gases which carry injurious germs into the air around us, their use should be strenuously opposed in all densely populated districts or where drinking water is obtained from wells which might be polluted by them. In many European cities cesspools are strictly prohibited.

A much better contrivance, and one which is supported by many sanitarians, is the storage in casks and pails, with a frequent removal at intervals varying from one to six days. This method is very common in Europe, and has been given the preference over all others by a number of prominent men. An inspection of the best examples in cities like Paris, Rochdale and Birmingham, Heidelberg, Stuttgart and Zürich, is convincing that they can, if properly designed and managed, answer

all sanitary requirements, and indeed their advocates are found to be principally among hygienists and physicians.

The applicability of casks and pails is not limited by any topographical but by social conditions. They become impracticable wherever the use of water-closets is the general custom, on account of the large additional amount of water discharged into them.

In Paris they use for about one-fifth of the population the so-called "*fosses filtres*" which are casks retaining only the solids and allowing the fluids to drain off into the sewers. They are mainly introduced to satisfy popular prejudice against fæces entering the sewers, which is presumed to create very objectionable exhalations. These "*fosses*" should be considered, as they undoubtedly are, a transitional contrivance towards the introduction of complete water carriage.

It may be questioned whether the casks and pails will ever meet with the same favor in our country as in the mentioned towns of Europe. For, in the first place, we have not the same rigid regulative conditions, and could not depend as well on the faithful and proper exchange of the pails, in short, on a management of this system which would make it much superior to well-built common privies. Then, we consider a liberal supply of water one of the first requisites of a growing town, and having this, the waste water and the gradual introduction of water-closets generally makes sewers preferable.

However, there may be cases where the pail system can be advantageous. But it will be limited to small towns, on account of the expense of cartage, and to localities which are expensive to sewer.

Finally, we must mention the appliances which, from a sanitary point of view, are the best under this head, namely, those where decomposition is retarded or arrested by the addition of disinfectants.

Two means can be employed, either preventing decomposition by absorption of the moisture, or conversion of the dangerous compounds into uninjurious ones. The former is accomplished by dry earth, charcoal, etc., the latter by carbolic acid, chloride of calcium, creosote, etc. To render disinfection efficient, it is necessary to add the material in sufficient quantities after every evacuation.

However good this method is, its expense in supplying and removing the additional materials precludes its extended application.

The well-known dry-earth closet is one of the best contrivances in use, because it is effectual in its object without being too costly. It can be

recommended for small country towns and isolated buildings, without a regular water supply or sewerage, and where the supply of fresh earth and the disposal of the resulting manure can be properly attended to.

II.—Immediate and Continuous Self-removal.

This is accomplished by means of "water carriage" or sewerage proper, and is made possible by the fact, that the usual amount of fluid waste discharged from the dwellings, which are furnished with a regular supply of water, is about sufficient to float or flush away the solid waste matter excepting of course garbage and ashes.

A continuous system of underground channels leading from the dwellings to a place of final disposal ought therefore to completely remove, with proper gradients, etc., all substances of the above nature, which by their retention might produce injurious effects. Yet, in point of fact, this has often not been accomplished, and the opposition to sewerage, especially from those who are mostly concerned about the sanitary question, has therefore been very strong.

This unsatisfactory condition of many sewerage works has caused still other disagreements. While admitting that the principle of water carriage is good, opinions differ as to the designs by which it is to be accomplished, whether the sewers shall also receive and discharge storm waters, or shall be limited to convey sewage alone, the former being termed the "combined"; and the latter the "separate" system.

Even the latter is represented in different forms. We have the "ordinary" separate system which is built on the same general principles as the "combined," excepting that the size of the pipes is proportioned for sewage alone, and that no provision is needed for the entrance or discharge of rain water, which is led off either over the surface, or in separate channels. It is much used in England, and has lately been adopted in Memphis, Tenn.

Then we have the Liernur system, which is used in several cities in Holland. It consists of iron sewers of a uniform diameter of 5 inches, into and through which the sewage is drawn to a central station by means of a vacuum created in them by an air pump. At this point it flows into barges and is taken to neighboring farms.

The composition of the sewage thus provided for, is different from that in other towns, as it consists solely of excreta and chamber slops,

and has therefore greater agricultural value. Water-closets are not objected to, although their use is discouraged.

A second system of pipes, similar to ordinary sewers, is proposed for removing the waste water from kitchens and factories, as well as the subsoil and rain water. This part of the Liernur system has never yet been built. It is easily seen that it alone could differ very little in design, extent, and therefore cost, from the combined system. For, as the quality of the supposed contents would nearly equal that of the present Paris sewage, which contains practically no fæces, and only a small proportion of urine, they would be nearly as foul, and the Paris sewage is sufficiently strong to require the same treatment as that from water-closeted towns. Wherever the Liernur system has been carried out, this underground house and rain water conveyance has not been very much needed, for topographical reasons. The expense, therefore, as usually given applies simply to the pneumatic system, or the removal of excrementitious matter alone.

The details of the works are ingenious, and their operation is satisfactory from a sanitary point of view. The closets, where the use of water is restricted, are not as clean as elsewhere, but otherwise no complaint can be made, as all excreta are quickly removed in pipes, from which no gases and germs can escape, and are collected at the out fall in a more valuable condition for agriculture than ordinary sewage can be.

The expense of Liernur's system, however, is to be its great objection. Besides the sewerage necessary for the rain and house-water, which alone would cost about as much as a regular "combined" system with its street inlets, man-holes and junctions, there are iron pipes, with reservoirs, chambers and valves, in every street. And the maintenance itself is expensive, for instead of using gravity to transport the fluid, this is done by means of a vacuum produced by artificial power.

The applicability of the system is limited to localities where the use of water-closets can be restricted, and where a purification of sewage is necessary. Enough experience is gained to know that it cannot compete with the ordinary gravitating systems on account of its cost, except, perhaps, in extraordinary cases, where the latter cannot be employed.

Another variation of the separate system is being introduced by Mr. Shone in England.

Its peculiar feature is the Shone Ejector, a patented automatic pump worked by compressed air, supplied from a central station. Its main advantage is to obviate the necessity of deep cuttings, by placing an ejector wherever this would be necessary, and raising the sewage to any convenient height, from which it can again flow by gravity. The automatic action of the pumps and the facility with which any number of them can be operated from one compressor may recommend it for certain conditions.

In low flat districts, where deep excavations may be very troublesome, perhaps through quicksand or water, a raising of a few feet now and then, could keep the sewer above the annoying strata. Also, in undulating territory, where the sewage is to be conveyed across several ridges, it may be preferred.

As Shone's system is too new to permit reliable conclusions, and Liernur's has very limited advantages, if any, over the ordinary "separate" system, we shall confine ourselves in the following to the latter and the "combined."

The objections against water-carriage have mainly been: A pollution of the soil around the sewers, the incomplete removal of the solids, which often makes the sewer an "elongated cesspool," the consequent dispersion of gases and germs from them through openings into the streets and houses, the pollution of the rivers by the discharge of filth into them, and the pollution of the air from sewage-farms.

The main points usually given in favor of water-carriage are: A greater cleanliness in and around the dwellings by the use of water-closets and the immediate underground removal of all waste water, a greater certainty in its removal on account of being automatic instead of dependent on human aid, and a greater economy in the case of populous districts.

From general observation, the superiority of water-carriage in cities seems evident, for its adoption is rapidly progressing even in towns where it has once been much objected to. But also a close examination of the executed systems shows them to be superior, and that sanitary objections are only founded on works that are imperfectly planned, built or managed.

The pollution of the soil has only been noticed where sewers were carelessly built; the deposit of filth in them is caused by improper grade, shape, or maintenance; the pollution of rivers arises only when

the sewage is improperly, or not at all, purified ; and the pollution of the air from sewage farms is found, if the latter are well managed, to be without any dangerous effects.

In our own country we have recognized the superiority of water-carriage over dry removal, at least from the point of view of being cheaper, and, as far as the dwellings are concerned, also cleaner, and it does not seem that the latter will ever be introduced to any extent. The only dispute which may arise among us will be with reference to the relative value of the several systems of water-carriage itself.

We will now give a glance at some of their guiding principles, for we think that the insufficient attention given to them has often caused the failure to satisfy sanitary or engineering demands, and, therefore, quite naturally has given rise to the attacks upon the entire system.

The general design can be materially effected by the manner in which the sewage is to be ultimately disposed of, and by topographical features of the site of the town. Different types are therefore found to suit different conditions.

When discharged into a comparatively large body of water, either river, estuary, or sea, purification can be ignored, as far as the sanitary question is concerned.

The only object to be sought is to prevent the solid particles of sewage from lodging along the shores. It can be accomplished in running water by an outlet near the main current and in tidal water by a discharge so far below the town that it cannot return, or by a temporary storage and discharge at or after high water.

It makes no difference in this respect whether the sewage is brought to the outfall from a separate or a combined system. Either is alike applicable from a sanitary point of view. The cost alone will govern their relative advantage when the sewage is thus discharged.

When, however, purification is required, the size of the river, the position of the town, its topographical features and existing works, will be factors in determining the value of the system to be preferred.

The use of the "combined" makes it necessary to intercept the sewage proper, and to lead it alone to the point where it is to be purified. The interception, however, cannot always be complete. During rains the sewage is more or less diluted, possibly not differing at all from that which is not intercepted and flows into the streams.

If the diluted sewage during storms cannot be allowed to run into the streams, then the separate system becomes preferable for health, and for economy also, when purification of the diluted sewage is costly on account of difficulties connected with the locality.

But if the occasional discharge of diluted sewage can be permitted in the rivers, and this will mostly be the case because it differs little, if at all, from the surface washings of towns and fields, then the combined system is to be preferred on grounds of economy, unless the question must be decided on other points.

Existing sewers, which can be used for rain-water, but not for sewage, on account of improper design or location, may cause the separate system to be cheaper, as comparatively small pipes are required for sewage alone.

When the town lies along the banks of a large body of water, or is stretched out along the foot of a steep slope, having in both cases very short drainage areas, from which the storm water can readily run off on the surface, it will be more economical to build sewers for sewage alone.

Thus it is seen that different features of the locality will be best served by different systems, provided they can equally well satisfy the sanitary demands.

This proviso must, therefore, be first determined, and on it there is as yet no unanimity of opinion. The filthy and unsatisfactory condition of many combined systems have been the cause of a belief that the principle is at fault; and greater satisfaction is expected from a more universal application of the separate system.

Our recent inspection of works on both plans has fully satisfied us that no decided preference can be given to either one, when equal care is applied to design, construction and maintenance.

The best works existing at present belong to the combined system, which are the sewerage of Frankfort, Hamburg, and Danzig, the main drainage of London, and parts of the works in other English cities.

The separate system, which has been advocated since 1851, when it was applied in Tottenham, has since been used in Oxford, Reading and other small towns. An inspection shows, also, their sanitary condition to be good, but no better than that of the before mentioned works.

The bad condition of many of our own systems can, therefore, hardly be due to the fault of a principle, but to faulty design or construction, or insufficient care in their maintenance.

We shall now allude to various principles, the neglect of which has been observed to give rise to these defects. When sewers are too small to be entered, they should have man-holes at every point of lateral deviation, and man-holes or lamp-holes at every change of gradient, the entire change taking place in the holes themselves by means of short curves. Between these points the pipes must be laid in perfectly straight lines, with additional man or lamp-holes, at distances not exceeding 300 feet, so that the whole system can be examined at any time throughout its entire length, without breaking open the street.

The importance of this principle, which was first recognized and consistently applied by Robert Rawlinson, has been fully demonstrated by long experience. One of its chief merits lies in the fact that it is based on actual experience, instead of pure theoretical reasoning. Numerous failures have been and are still traced to its being neglected. The instances are many when it was thought impossible that small pipes, with all their entrances guarded and screened, should ever get choked, and yet it is a frequent occurence, in spite of the strictest regulation and care.

Another principle of alignment is gained from the fact that a sewer of x times the capacity will not cost x times as much money. It will be economical to lead as many sewers together into mains as possible, instead of keeping the sizes more equal.

With the same lengths of sewers, not only a reduction of cost can thus be gained, but also the concomitant advantage of having better gradients for the smaller sewers or branches, where they are most needed, which contributes to the sanitary efficiency of the system.

Still another point presents itself in the alignment which should be kept in mind. A great velocity of the sewage, when changed to a slight velocity, causes a subsidence and deposit, which is one of the first things to guard against in a perfect system of sewers.

It is, therefore, important to give the sewers a greater length, *i. e.*, less grade on the sloping grounds, in order to equalize the velocity with that in flatter grounds as much as possible. This does not necessarily imply a greater length of sewers for the town, but only a different distribution.

Finally, we will mention a system of alignment used by Mr. Lindley in Frankfort and elsewhere, by which the troublesome dead ends of the branch sewers are avoided. Instead of allowing the latter to terminate

abruptly, he unites them with the sewers of the next higher section. By this means it is possible to flush the branches, whenever necessary, with a copious flow from a main above. A disadvantage accompanying this system is a loss of grade to the former, but the possibility of giving a powerful flush at any moment will mostly outweigh it, when the gradients become flat. The summits of the system are by this method reduced to a minimum and the water for flushing them is obtained, in Frankfort, for instance, from the subsoil, and is allowed to accumulate in a porous brick reservoir.

Although this method of alignment is rather expensive, especially when consistently carried through, it may often proportionately reduce the cost of maintenance. The excellent condition of the Frankfort sewers is greatly due to this facility for thorough flushing. Fields' flush tanks have recently been elsewhere introduced to overcome the same trouble of dead ends, partially with good effects.

All of these points apply more or less to both the combined and separate systems.

The gradients of sewers next give occasion for a few suggestions.

As the grade which is necessary to give proper velocity to the ordinary flow of sewage must answer other requirements than the grade necessary to remove storm water, a distinction between these should be made.

In the former case it is limited by a minimum which is sufficient to move the usual sewage fast enough to prevent deposit, unless other means of assisting its removal must be resorted to, as, for instance, in very level districts.

The grade of the sewer invert can usually be considered as equal to the one causing the velocity, although there are cases, as in Hamburg and Westham, near London, where the former is a dead level, in order to allow the sewage to flow in either direction as may be required, and when the velocity must be determined from the hydraulic gradient.

The storm water discharge which regulates the size of the sewer, should have its velocity calculated from the hydraulic gradient. This is especially necessary when the outlet is partially or entirely below high water level of the river.

By not considering this distinction the capacity of sewers during storms has often been materially impaired, although intended to effectually discharge the water. And it has given cause for a foul condition

due to slack water, which was laid to the fact of attempting to lead storm water and sewage into the same channels instead of to an improper design of the works.

The size of the sewers, after the grade had been considered, depends on the quantity of water to be conveyed, and causes the main distinguishing feature between the two systems.

Where sewage alone enters, the size is determined from the maximum flow per second which is likely to occur at any hour or day. It will therefore vary with the density of population.

Where storm water is to be led into the same sewers, the amount of sewage itself becomes so insignificant that the size can be regulated by the former alone. The amount of storm water for which allowance should be made is not yet a settled question. There has often been trouble from this cause, for when too small, the sewers are likely to cause flooding, and when too large, a deposit and resulting decomposition. A satisfactory range of experience is yet to be compiled on this point.

Self registering rain gauges, stationed at near intervals over a comparatively large drainage area, together with a gauging of the storm water discharged by the sewers, can alone furnish a reliable guide. By thus observing the extent, intensity and movements of storms, and their corresponding effects in the sewers at different seasons from different slopes, paved areas, lawns, &c., a scientific proportioning of sewers would be more possible than now.

In the meantime, the next best information is very acceptable. We have recently obtained an empirical formula from Mr. Burkli-Ziegler, which may do good service as a guide where sufficiently extensive observations have not yet been made.

Having collected data on the intensity of some heavy storms, and the corresponding discharge of sewers in Zurich, he collected whatever other information he could obtain from other European localities, and found the following relation :

$$q = c\,r\sqrt[4]{\frac{s}{a}}$$

wherein,

q=water-reaching sewer in cubic feet per acre per second.

r=average intensity of rain during heaviest fall in cubic feet per acre per second.

s=general grade of drainage area in feet per thousand.

a=area drained, in acres.

c=coefficient, for average cases=.625

The range of observations was limited to comparatively small areas, and included some of the heaviest known rainfalls. The slopes of the areas extended to 10 feet per hundred. He proposes the coëff. c=.625 (for English measure), as it covers most of the observations, but for paved streets in London finds it to be .75, and for suburbs with lawns and unpaved streets, as small as .31. The values of r which he recommends for Switzerland and Central Europe are an average intensity of $1\frac{3}{4}''$ to $2\frac{1}{4}''$ per hour, depending on how far provision is deemed expedient for extraordinary storms.

The principle which the formula embodies is to give to the fraction of the rainfall which enters sewers a decreasing proportion per acre per second for an increasing size of the drainage area, a fact which in general has been long recognized.

By an intelligent use of this formula, somewhat more rational sizes can be obtained, than by the rule of three, which is yet so commonly applied to areas covering thousands of acres, but which is only reasonable when the areas are very small. In the latter case when the areas are less than say 20 acres, a simple proportion is probably better than the above formula; *i. e.*, the rain-water entering the sewer will be about in a direct proportion to the area from which it flows off.

In connection with this another point must be mentioned. The longer we can keep the rain-water flowing on the streets, the less provision is necessary for it under ground. Therefore, it is advisable to prevent its entrance into sewers as long as practicable without flooding streets, endangering basements, or otherwise causing trouble.

Whether gutters, open or covered, can be allowed to cross the streets is a question for each municipality to determine. They are decidedly objectionable, however, in main streets, and in large cities the tendency has been to abolish them wherever they existed. When gutters receive nothing but rain-water, the latter, when it comes from a few blocks only, can generally be led across the street junctions of a good and smooth modern pavement without any trouble. Especially near the water-shed line of the drainage area good use can be made of this consideration, by a proportionate reduction in the size of the pipes.

The foregoing remarks on the size of sewers for the combined system, show that it may often be safely reduced, especially in the lower parts of large drainage areas, which not only saves expense but improves the sanitary condition, by getting a more rapid flow and less exposure of surface for the same quantity of sewage.

We have now to inquire into the main influences effecting the velocity other than the grade which has just been considered.

An acceleration produced by the water entering the many connections will be slight, if at all perceptible; the retarding influences, however, deserve very careful inquiry, as they greatly affect the sanitary condition and perfect working of the system. Whatever enters a sewer should be steadily carried along to the outfall without the retention of a single particle.

Connections should therefore be placed so that the entering water has a direction as near as practicable to that of the sewer and a velocity at least equal to it.

Junctions of sewers should be made either with as large a radius as possible, when they are capable of being entered, or, with an extra fall to counteract the corresponding loss of head, as their radius diminishes, which latter is the only proper expedient for pipe sewers. In order to produce no backwater, the smaller sewers should deliver their daily maximum discharge at least at the same elevation as the larger ones.

A most important influence on the velocity of the sewage is found in the degree of roughness of the sewer's perimeter. By a smooth surface not only a greater velocity is gained, but an adhesion of organic matter is greatly prevented, causing what in Germany is known as the "*sielhaut*,"* and which is claimed to be the greatest impediment in the way of making water carriage successful, from a sanitary point of view. Therefore, the smoother and more regular the surface, the better. Glazed pipes are good for this reason when their joints are even and do not project. Concrete sewers, as built in Paris and Vienna, where they are continuously moulded in the trench against planed iron sheeting, are excellent. Brickwork should be built of the best bricks, carefully jointed; and rough brick or stone work ought not to be permitted, as through it most of the trouble laid to the combined system, as such, has been caused.

* Slimy coating along the sides of sewers.

The section of sewers offers the following points for comment. The proper conveyance of the daily flow should be in a circular or semicircular channel, just large enough to hold it, because this form gives to a certain amount of fluid its greatest flushing power, the importance of which for the heterogeneous body of sewage cannot be overestimated.

The section for sewers receiving nothing but sewage, should therefore be circular, assuming them to run full or half full.

When rain-water is to be occasionally admitted, the same semicircular section of the same size, which was found best for the conveyance of a certain amount of sewage, in the first case, should be preserved also in this one. To convey the rain-water, the necessary space should be provided for, above this channel required for the sewage, but without materially changing its form or size. An egg-shaped section is thus obtained, together with the elements which designate its proportions. The invert should become more pointed as the relation between the quantity of daily sewage and maximum rain-water becomes greater.

Many of the sections commonly used are made too flat in the invert and therefore give but a slight advantage over the circular form. The latter, although still used at some places, is quite inappropriate for the combined system, because it permits the daily flow to spread out into a shallow stream, reducing its velocity and by a continual variation of level, causing deposits along the edges.

These results are often quoted as inherent defects of sewers which receive such differing quantities as sewage and rain-water in the same channels. Yet it will be seen, that if the sewage itself in both systems, is led off through sections substantially alike in shape and size, the effects cannot be very different. Only after storms, when the floating particles may, while the water subsides, strike and permanently adhere to the sides, a troublesome effect can be caused. But our inspection showed clearly that when the surface is smooth, this adhesion is practically insignificant to sight, and was confirmed by the slight odor always perceptible in concrete or other smooth sewers as against those with rough perimeters.

The effects of flushing in the two systems will not differ much, if the inverts are alike. A small quantity of water as discharged from flush tanks or chambers at the heads of branches, will have about the same cleansing effect in either case. In the separate system, *i. e.*, in small

pipes, an advantage is gained by being able to flush under a head, and thus obtain for a smaller quantity of water a greater velocity. In the combined, an advantage is had from the periodical flushing by storm water, which is very effectual, and, in fact, is the only manner by which sewers get cleaned in many of our cities.

In wrongly designed sewers this rain-water flushing is not sufficient to cleanse them, and even in rightly designed sewers, it cannot be solely depended on, and it will be necesary at times to clean sewers from substances too large or heavy to be removed by flushing water. It is an indisputable fact that such obstructing bodies will get in, although carefully provided against, and there must be some ready means to take them out. In large sewers removal by hand is the quickest and cheapest way. Where they cannot be entered, it is necessary to push or pull brushes or other implements through, or to let a wooden ball of slightly less diameter float through them, as is done in some English towns, and in the large syphon under the Seine, at Paris. Small sewers, therefore, require to be accessible at frequent intervals, to permit this cleaning, and avoid a breaking up of the street and sewer.

As a large proportion of the sewers of a combined system can generally be entered, and thus allow the unavoidable obstructions to be more readily removed, it deserves preference in the direction of maintenance.

The question of ventilation also offers some points of comparison.

Generally speaking, the exhalations from sewage will vary with the bulk and surface exposed to the air, but not with the quantity of air above it. The large quantity of the latter in the combined sewer, therefore, does not necessarily contain more impurities, as has been asserted, than the small amount of air in the separate sewer, other things being equal.

It is true that the former has more decomposing matter adhering to its sides, but it is also true that it has a much larger proportion of air to dilute the resulting gases. As a matter of fact, the odor emitted from small sewers is more offensive, because more concentrated, than the odor in large sewers, both being in good order.

The degree of foulness of the sewage depends on its age, on the rapidity with which it is discharged, and on the proper construction of the works generally. The dangerous condition of the air, *i. e.*, the amount of impurities contained in it, will, therefore, likewise depend on these circumstances, rather than on its relative volume in the sewer.

As a free circulation of air is always necessary, ready means of egress and ingress should be provided, not only to remove the gases and germs, but to yield to the fluctuations of the sewage. In well built and maintained sewers, open gratings in the roadway have not been found objectionable. In some cities, as Paris, Hamburg and Leeds, the rain-water inlets along the sidewalks are without traps, and permit a free communication with the outside air. In a number of towns in Germany the circulation is also facilitated by the main house drain pipes, which are untrapped and carried above the roof. Special appliances for ventilation, as chimneys, etc., with natural or artificial draughts, which are found to act at best for a very short distance, have more or less been abandoned for the idea that frequent small openings in the streets are more efficient and less expensive, especially in connection with ventilation obtained through house drains.

The objections to this manner of ventilating the sewers come mainly from the advocates of the dry removal, or the Liernur system, in both of which sewer air cannot exist in the street. Yet their objections are only substantiated by works that are not properly built or maintained, and, on the other hand, the exhalations from the Liernur closet, when the use of water is limited, and from the casks and pails in the dwellings themselves, are at least as objectionable, if not more so.

If ventilation can be carried out as stated, it will, therfore, be of little difference to which system the method is applied, and the purity of the escaping air will depend far more on the way in which either is designed or kept in good order.

A few more points remain to be considered.

Where it becomes necessary to prevent storm water from running through the streets and over the crossings in closely built up districts, it must be carried away in underground channels. In the separate and combined systems, equally, provision must be made. In the former case separate channels are required, for which old and otherwise useless sewers may be used, or when newly built they can be only slightly below the surface. Although no sewage is allowed to enter them, yet they receive from the streets an amount of putrescible matter, which requires them to be built on similar principles and with similar care to the regular sewers. The rain water channels examined in Oxford and Reading, the best examples, were not as odorless, when seen in dry weather, as the sewers in Frankfort and Hamburg.

The rain-water from the streets enters the sewers through inlets at the curbs. The designs of these inlets will differ according to circumstances. In Hamburg, where the streets are well paved, the sewers well designed, and where there is an unlimited supply of water in the Alster basin which is used for frequent flushing, it is possible to lead the surface water directly into the sewer without silt basin or trap. In Paris, where it is preferred frequently to wash the street dirt into the sewers instead of carting it away, and where, with the "*bateaux* and *wagons vannes*" a good system of artificial flushing is in use, the silt basins and traps are also omitted, with no objectionable results.

In cities where the same facilities are not had, and where neither streets nor sewers can be cleaned as well, silt basins are necessary to retain all heavy and bulky materials.

The size will depend on their frequency, on the character of pavement and the facilities for cleaning them; their depth must be below the frost line. If not properly attended to they may be very objectionable, yet this feature is common to both systems, when rain-water is led away under ground.

Where sewer exhalations are strong, it will be necessary to insert traps at the inlets to prevent a nuisance along the sidewalks. But this necessity should always be considered capable of being removed by improving existing defects in the system, because the absence of traps, by assisting ventilation, will promote the sanitary condition of the sewer.

It will be seen from these remarks that basins and traps should be avoided, if possible, by making them unnecessary through a good system of cleaning the sewers, and by keeping the rain-water on the surface as long as practicable, the number of inlets themselves could be reduced. The latter necessitates good pavements with slight camber to enable the water to cross intersections, as seen in London, Berlin and Paris. This is particulary advantageous near the summits of the drainage area where the proportionate reductions in the size of the pipes, and therefore saving of expense, will be greatest.

In reviewing what has been said about the combined and separate systems, it is clear that an earnest opposition to either, on sanitary grounds, is not justifiable. If there is any preference it is in favor of the combined system, because it offers on account of the size of the sewers, greater facilities for inspection and cleaning, and decreases the probabilities of stoppages.

A choice will therefore depend mainly on the question of cost, both of construction and maintenance. And in the latter case consideration should be given to the fact, that simplicity of a sewerage system in its design, and as much independence as possible from human aid in its working, can represent considerable value.

Finally, it may be stated that a comparison of our works generally with those in Europe, shows that the chief cause of their unsatisfactory condition lies in the insufficient attention given to maintenance. In this direction, therefore, we need the greatest improvement. Constant care is necessary to preserve even good works in a good state. From the very nature of sewage, in being probably the most heterogeneous substance in existence, this cannot be dispensed with. It will be as obligatory in one system as in the other, but its expense will depend less on their difference than on the manner in which either has been originally built.

General Comparisons and Conclusions.

It now remains to briefly draw a few comparisons between all the systems, and in so doing, it is premised that each one is designed, executed and maintained in a reasonably perfect manner. They are first compared from a sanitary point of view, and then as to their relative expense.

An inspection of the best examples will, we believe, convince one that each can be made to answer the sanitary demands within satisfactory limits, but that the water-carriage system is always preferable to the dry methods on account of its greater cleanliness in the houses and the quick, continuous removal of the filth.

Among the water carriage systems themselves, there is little difference if they are equally well built and maintained.

The Liernur method is least satisfactory, because the use of water is limited, and many foul substances are left to enter the rain-water channels. But on the street it gives less rise to offensiveness because of the impossibility of gases, if such there are, escaping through any opening.

The ordinary separate system is preferable from a sanitary point of view, whenever rain-water does not need extensive underground removal, when it is necessary to have a system of house drainage with the least possible delay, and when the diluted sewage during storms cannot be permitted to run into the streams.

Its disadvantages have been found to be as follows : The smaller pipes

increase the possibility of stoppage and disorder, and decrease the facilities for cleaning. Duplicate sewers for sewage and rain-water have also been the cause of erroneous connections and, if not absolutely water-tight, have acted and reacted on each other under the street. The channels carrying rain-water alone, including the street wash, will generally become foul if not given nearly the same attention as the combined.

The combined system, on the other hand, is best, from a sanitary point of view, for large areas of thickly populated surfaces, where underground rain-water removal is required. It has the advantage of being only a single system of sewers, which therefore avoids connections to the wrong system, and greatly facilitates maintenance in being more readily inspected and cleaned, both artificially and by the periodical rain storms.

Sanitary imperfections occur only when it is wrongly designed, and badly built or maintained, difficulties to which the duplicate system is also exposed and, from its greater complications, even in a greater measure. Objections made to the combined system, when purification is required, can usually be answered by properly designed intercepting sewers, which receive the foul waters alone, except during a heavy storm, when the sewage is so diluted, that it does not differ materially from the water running off the fields, and can, except in rare cases, be admitted into the stream without fear.

A comparison of the relative cost of the different systems depends so much on local conditions, that it is impossible to state more than very general results. Even with a full knowledge of the locality, it will sometimes require a careful consideration of circumstances to decide which one will be the most desirable and economical.

For a town where, from its position, water supply and density of population, water carriage is at all practicable, it will be less expensive, in spite of its greater first cost, than dry removal, provided the latter would be kept up to a good sanitary standard.

Among the water carriage systems themselves, the relative economy can be decided as follows :

Where storm water must be carried away under ground, as from extensive and closely built up districts, and when new sewers must be built for this purpose, as is generally the case in large or rapidly growing cities, the combined system will be the most economical.

Where storm water can flow away in existing sewers, which are unsuitable for the proper conveyance of sewage, or, when it can be

concentrated in a few channels, slightly below the surface, or can be allowed to run off over the surface, or finally, when purification of sewage becomes very difficult and expensive, it will be more economical to adopt the separate system, *i. e.*, to exclude the rain-water from the sewers receiving house drainage. These conditions will generally be found in towns which have an old system of valley line sewers, or have drainage areas which are very short, very steep, or so flat and low that no sewers can get an outfall without pumping, and finally, in rural districts where the population is scattered.

The separate system will also be the cheapest where necessity arises for a rapid drainage of houses, leaving rain-water out of the question at the time. But if the conditions demand an after provision for storms, by extensive sewers, the final cost will be greater.

When the sewers for rain-water alone must convey as much water as those of the combined system under the above conditions, and works to this effect have to be built anew, there can be no doubt of the greater expense, and although frequently proposed under a presumption of obtaining greater sanitary benefits, such a duplicate system has not yet been carried out, and according to the above conclusion, does not seem warranted.

It is possible, further, to make a combination of both systems in the same town. On some areas it may be found expedient to exclude rain-water and carry it on the surface into a water-course; on others, which are longer, and include closely built up territory, the combined system may be advisable, and the sewage of both can be united and continued in the same channel.

The cost of the Shone system, which has not yet been extensively tried, would be substantially the same, under the conditions where it is best applicable, as that of the ordinary separate system. The extra cost of compressed air tubes and machinery would be somewhat compensated by a saving of excavation.

Liernur's system is found to be the most expensive to construct, as it requires an iron pipe in every street, and two in those containing the discharging pipes from the numerous reservoirs, besides a system of ordinary sewers for taking away kitchen waste, and, if necessary, the rain-water.

The cost of maintenance for the different systems is even more difficult to estimate generally.

But, leaving dry removal, which is, of course, the most expensive, we can say that it is cheaper to maintain the combined system than the separate, because there is only one set of sewers, and, being large, they are easier to inspect, and less likely to get stopped up. Expense of flushing will usually be the same in both, but the combined has the additional advantage of the scouring of heavy rains.

The cost of maintaining the Shone system will be greater, than by using the ordinary method of pumping, yet other advantages may balance this additional expense in some localities.

The Liernur system again, is also the most expensive to maintain, as the motion of the liquid is produced by artificial power instead of gravity, even where the latter could operate alone on a down grade; yet this greater cost will be somewhat relieved, as the pipes do not require flushing or cleaning, and a greater return is had from the slightly richer manure.

Finally, the general conclusion which can now be drawn with reference to all of the systems, which is also, it appears, the direction in which an ultimate agreement in the various controversies may be found, lies in the fact that none of the above systems will be applicable for all towns, but different external conditions will demand as radically different solutions, both in general and detail. The dry removal and the separate and combined water carriage will each be satisfactory when confined to certain limits, and where each one will have advantages over the rest.

It may become necessary in some cases to make the most careful inquiry into the existing conditions before a decision can be arrived at, regarding the general system, as well as its details, which will be best suited to the particular locality.

When it is urged at present that a radical change is necessary in our method of sewerage, and that, for instance, the separate system should be adopted under conditions for which we have above designated the combined, it rather seems that this radical change is more necessary and will produce more beneficial results in the direction of improving the details of design, construction and maintenance of the latter, the neglect of which has been the main cause of its shortcomings. And this greater attention and care would, in fact, be no less imperative with the separate and all other systems.

But another change seems to be still more urgent. Although profess-

ing to favor water-carriage, the prevailing method in most American cities is still the use of the most objectionable of devices, the ancient cesspools under or near our dwellings. To abolish them where sewers are within reach, by substituting a carefully planned house drainage, will do more towards raising the sanitary condition of communities than the supposed difference between the two general systems of drainage which presents mainly a question of expediency and cost, because both may be equally good when well designed and managed, and equally bad when neglected.

DISCUSSION.

Charles E. Fowler.—We have in New Haven, Conn., a system of sewerage designed by Mr. E. S. Chesbrough, a member of the Society, which has been working well for ten years. It is what is known as the combined system, and we have not, as yet, experienced to any great extent, the difficulties complained of by the advocates of the separate system. We do not find that filth from the catch basins accumulates in the sewers to an extent sufficient to cause trouble. The principal cause of obstruction in our sewers, and I might say almost the only one, is sand, which reaches the sewers through the catch basins during heavy storms. The water in the catch basins, including any filth that may have accumulated there, is generally carried off in the early part of the storm, and it is only toward the end of the storm, when the basins are filled to overflowing, that the sand gets in. Sand from the basins is removed as soon as practicable, and the basins immediately flushed and filled with clean water from the fire hydrants. Our arrangements for removing the sand from the sewers, and cleaning them, are quite complete, and the work is carried out in a very economical and satisfactory manner. A thorough examination is made, and all sewers cleaned, at least once in each year. In the flushing of the smaller sewers, which cannot be entered by men, we are greatly assisted by the use of wooden balls, two inches less in diameter than that of the sewe

to be flushed. The wooden ball is placed in the sewer and forced from one manhole to another, by water closely confined and discharged in large quantities in rapid succession. The sand forced down is removed from the sewer at the manholes.

New Haven, being somewhat peculiarly situated, could not very well be sewered under the separate system, by a single line of soil pipes. It would be necessary to construct another line for the removal of the storm waters and surface drainage, as there are large areas to be drained that are at a considerable distance from the outlets. In fact, the territory wherein occurs the greatest inconvenience or damage from storm waters is situated at the greatest distance from the harbor, and one of our largest main sewers leads to that district.

Mr. Hering has referred to sewers with "dead ends," and advises that connecting links be made between the ends of the sewers, and sewers in adjoining streets. This plan has been tried at New Haven, with favorable results, the connection being made so as to act as an overflow. The sewers in our system are arranged in a manner to avoid, as far as possible, the construction of "dead ends," as in most cases, the culvert from a catch basin is brought into the end of the sewer. The main sewers, in most cases, being laid out through sections of the city having the least elevation above tide water, there are cases where the lines pass through unsettled portions, and, as might be expected, considerable opposition from land owners is encountered. Of course, the opposition is mainly on account of the expense of the assessment for the sewer, and when it becomes necessary to construct the mains for the relief of thickly settled districts beyond, such objections have to be overruled. In this way we may have to build a half mile, or even a mile of main sewer, where there are very few houses, in order to reach a section of the city needing drainage.

The concentric laying of pipe sewers, especially those of twelve and fifteen inches in diameter is, in my opinion, objectionable, where any great difference exists in the diameter or form. In burning the stoneware pipe, the tendency is to shrink unevenly and to warp. In our sewer contracts, it is provided that the area of the pipes shall not be less than that of a circle of the specified diameter, and the variation in diameter shall not exceed one-half inch. As many of our sewers are laid at minimum grades, and as irregularity in the joints would be liable to cause obstructions, our plan is to prevent, as far as possible, such obstruction

to the flow by laying the "water line" or bottom of the pipe true to the established grade.

Considerable trouble is experienced from foul air in the house drains, but we have had very litttle cause for complaint from its presence in the sewers.

Our greatest trouble just now is from manufacturing concerns turning hot water and steam into the sewers, which is found to seriously injure the cement pipe sewers, and the cement mortar, in the brick sewers.